

# (12) UK Patent Application (19) GB (11) 2 353 862 (13) A

(43) Date of A Publication 07.03.2001

(21) Application No 0011378.7

(22) Date of Filing 12.05.2000

(30) Priority Data

(31) 19922341 (32) 14.05.1999 (33) DE

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(51) INT CL<sup>7</sup>

G01C 3/02 15/00

(52) UK CL (Edition S )

G1F F1F

(56) Documents Cited

EP 0977011 A1 DE 003628350 A JP 080327352 A

(58) Field of Search

UK CL (Edition R ) G1F

INT CL<sup>7</sup> G01C 3/00 3/02 15/00

On-line: EPODOC, WPI, JAPIO

(54) Abstract Title

**Video-image surveying**

(57) The invention relates to a method and an arrangement for determining the spatial coordinates of at least one object point from the coordinates of at least two base points which serve as reference points and do not lie in one plane, with the aid of a video tachymeter which is disposed in a recording station, can pivot about a vertical axis StA and comprises a distance measuring arrangement, a video camera 6 comprising a CCD matrix 9, a target device and angle measuring devices, wherein the video camera can tilt about a horizontal axis.

The coordinates of any object points  $P_1, P_2$  are derived from base points  $B_1, B_2$  in the terrain which are measured and marked in each case by means of a reflector, laser spot, etc. In addition, a target image, which contains the marked base points and the object points is recorded and stored. The coordinates of any object points are then determined from the position data (coordinates) in the target images which are contained in the target images of the marked base points which have been determined using the tachymeter.

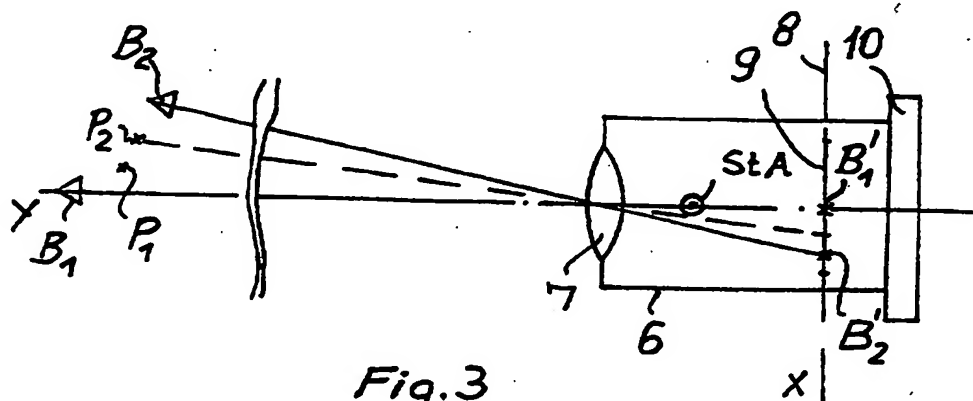


Fig. 3

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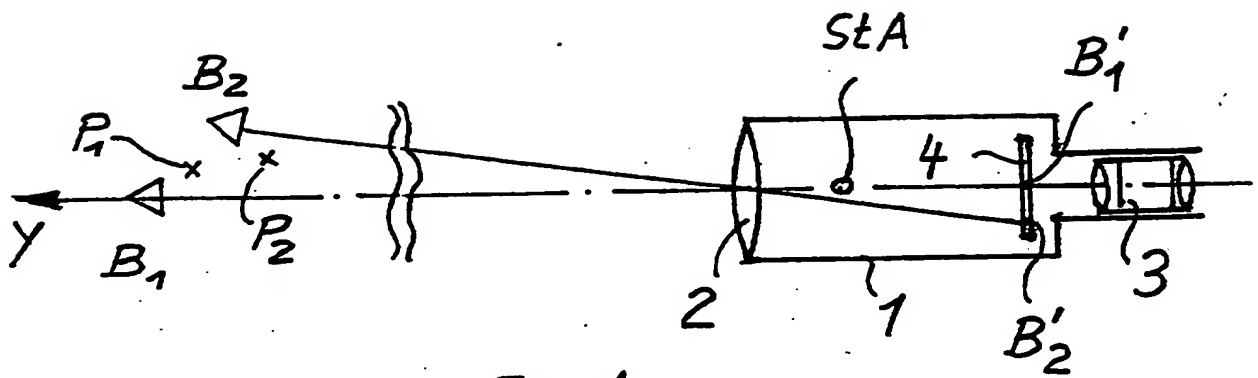


Fig. 1

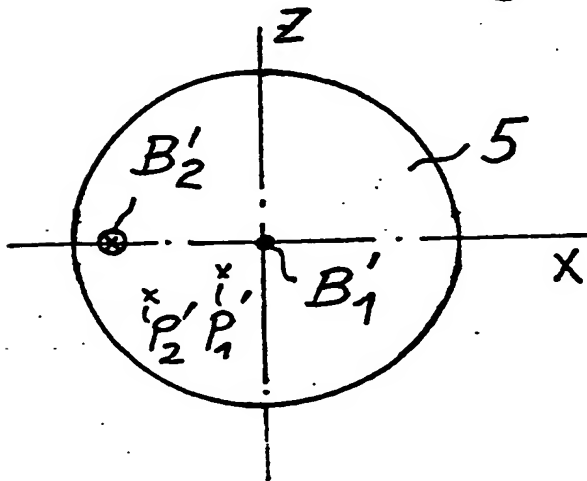


Fig. 2

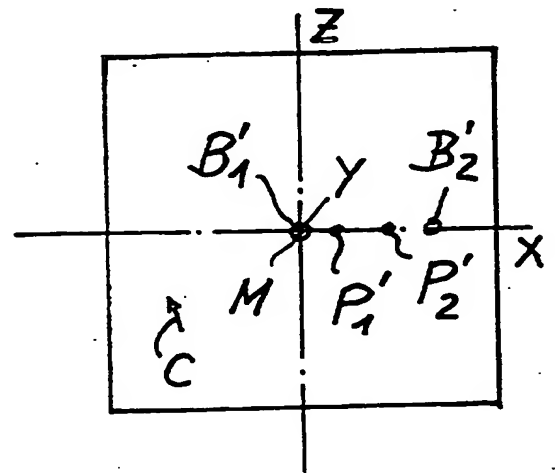


Fig. 4

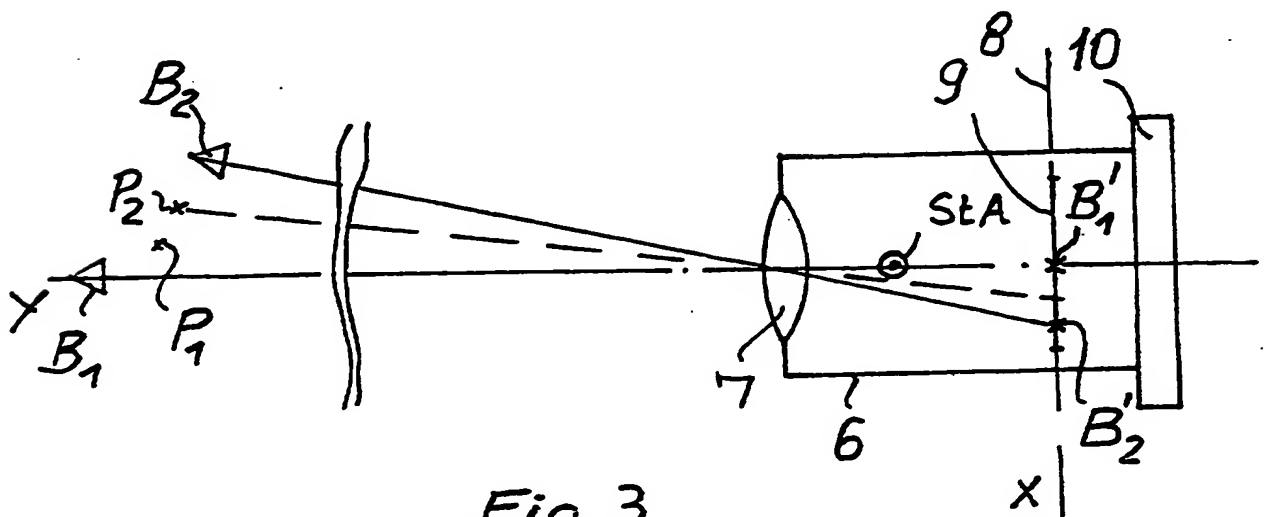


Fig. 3

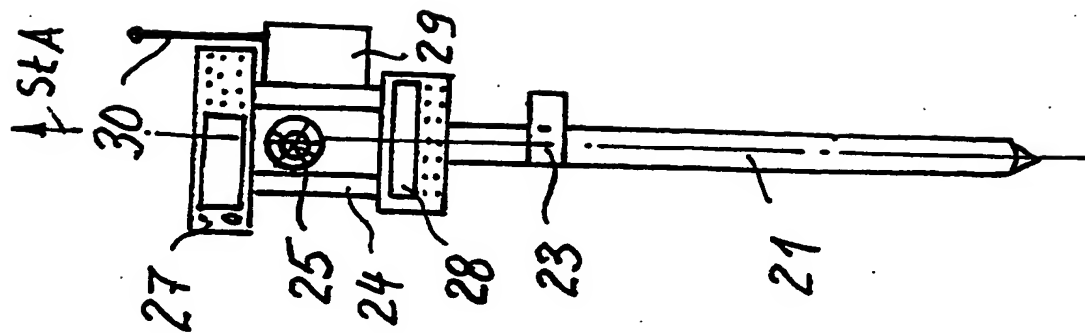


Fig. 5a

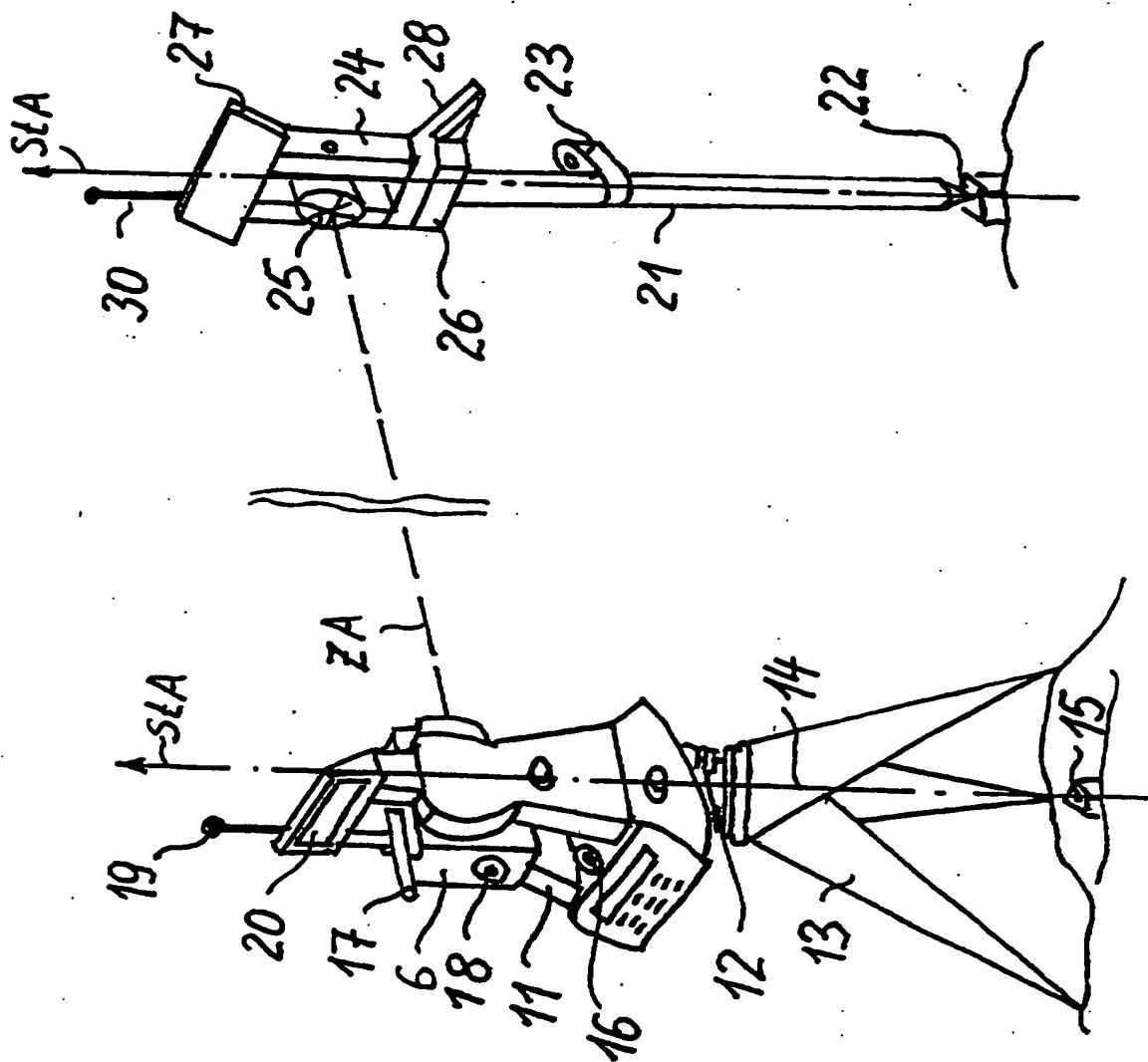
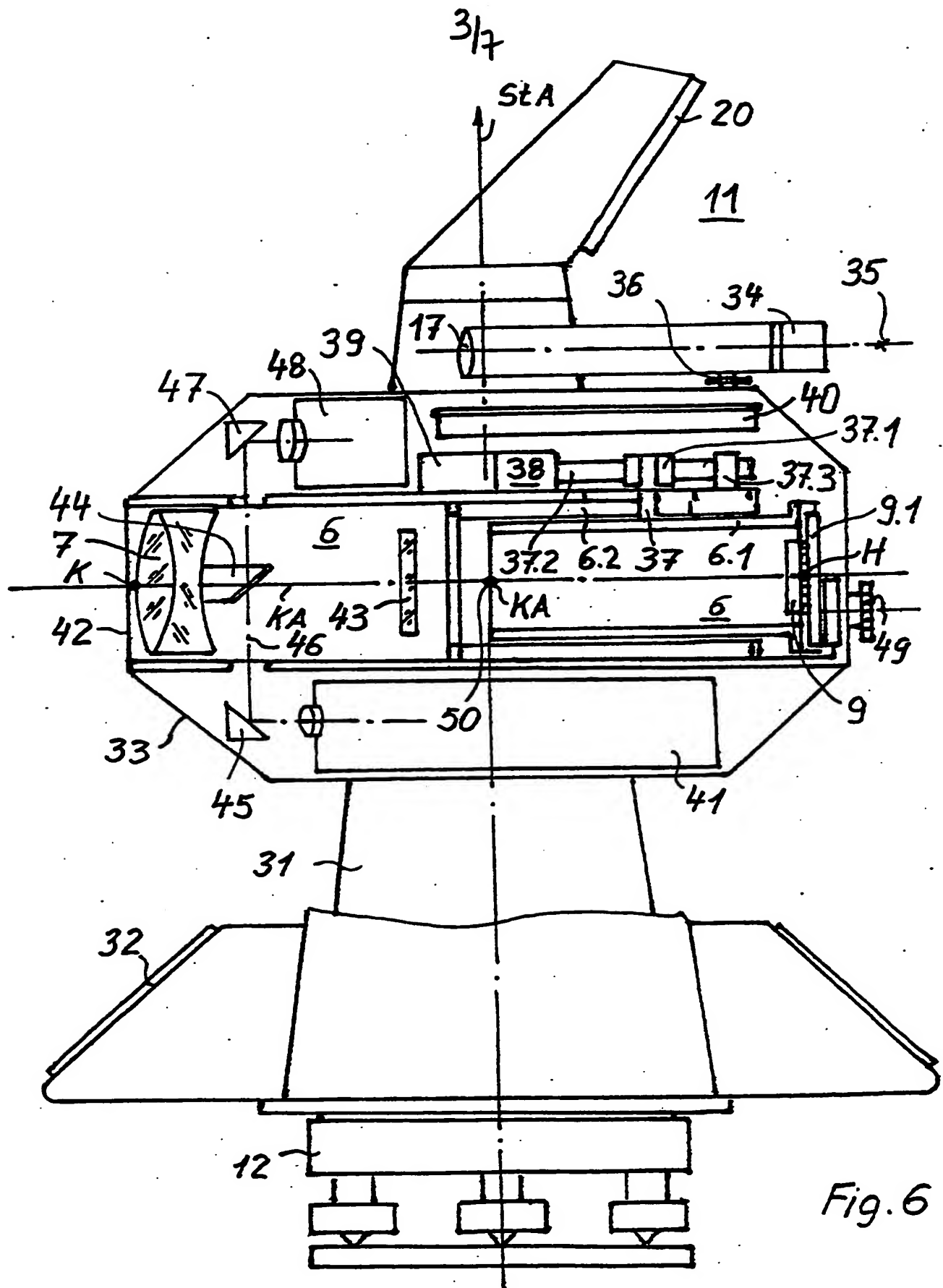


Fig. 5



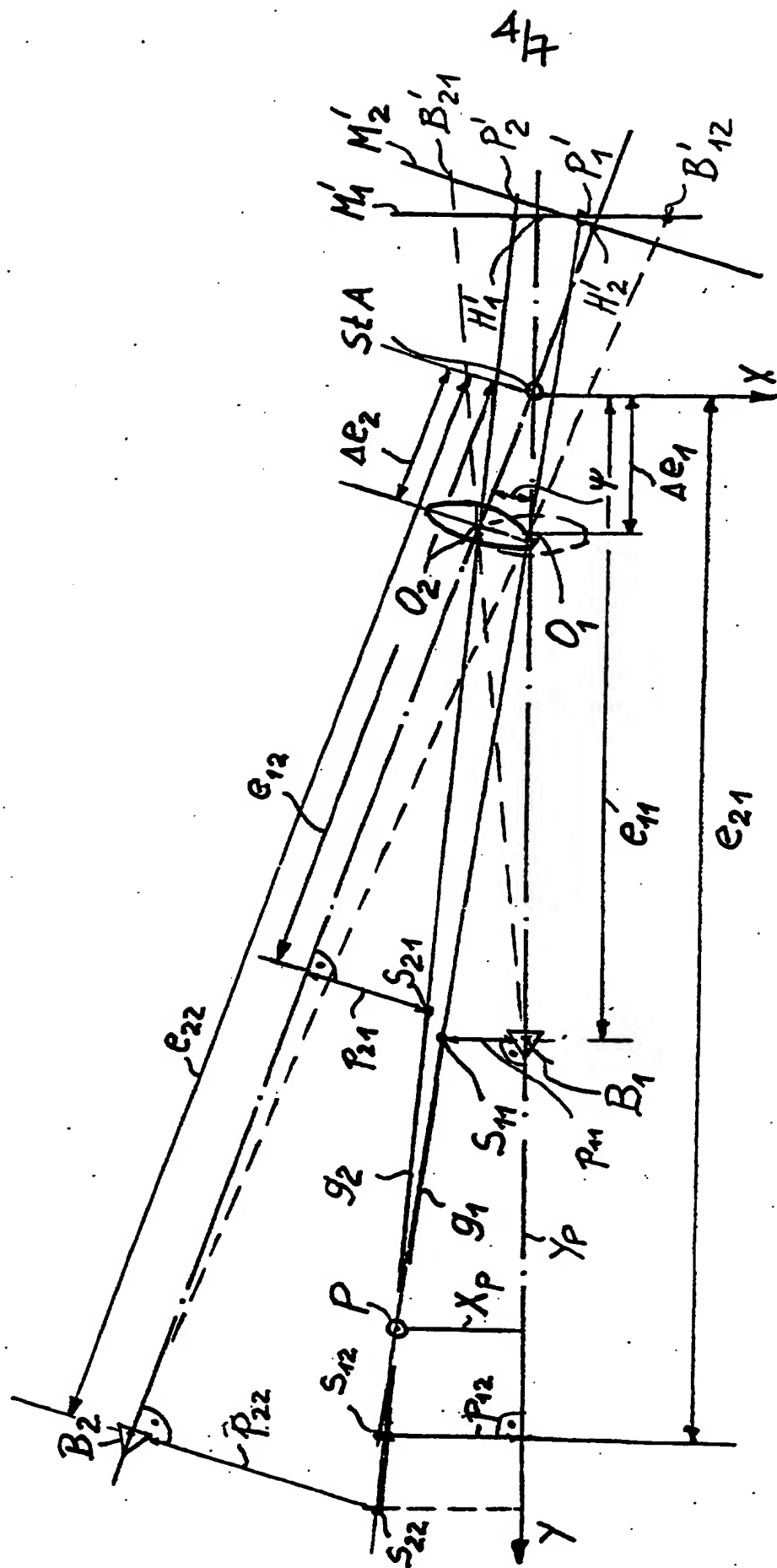
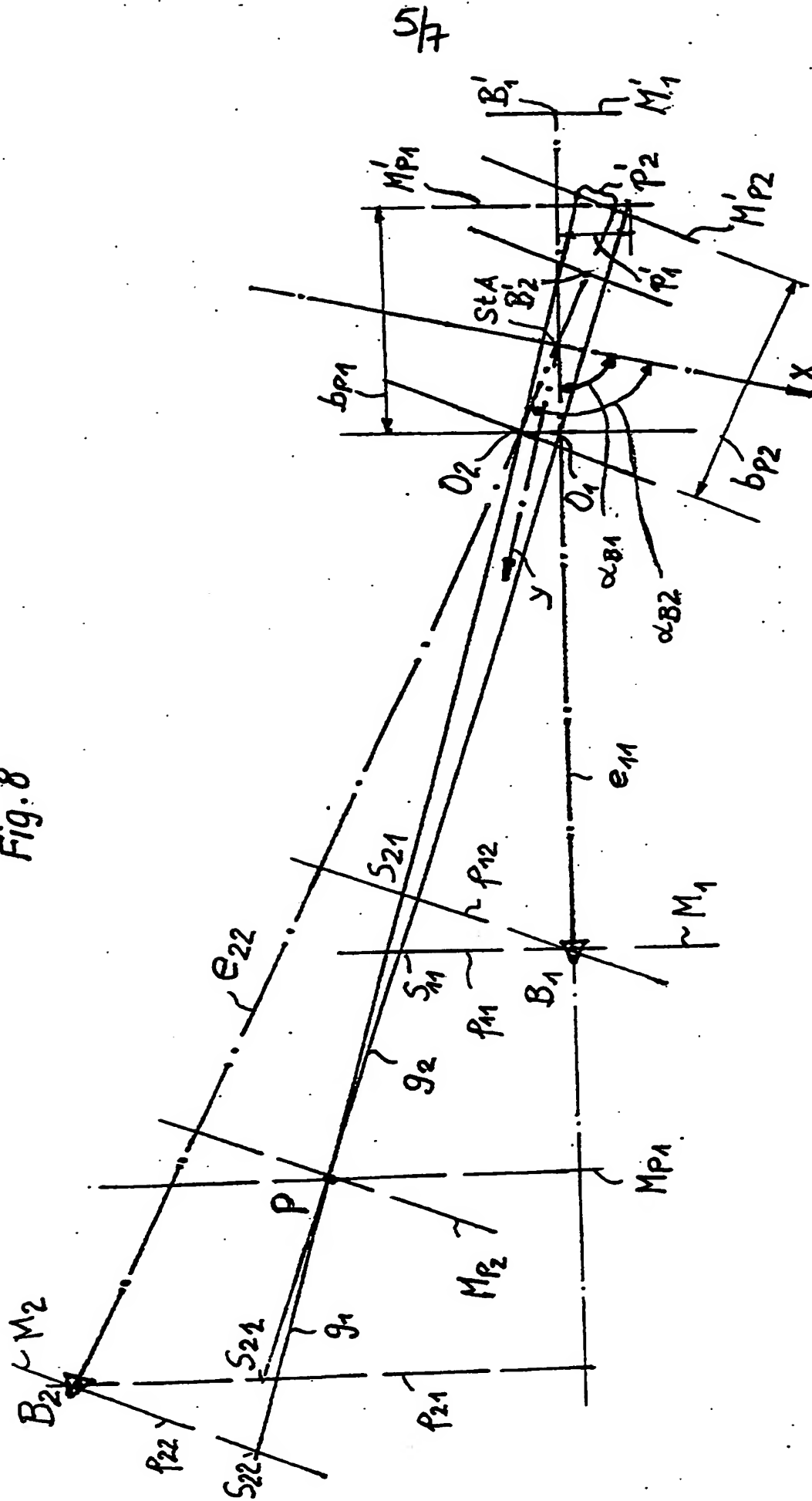


Fig. 8



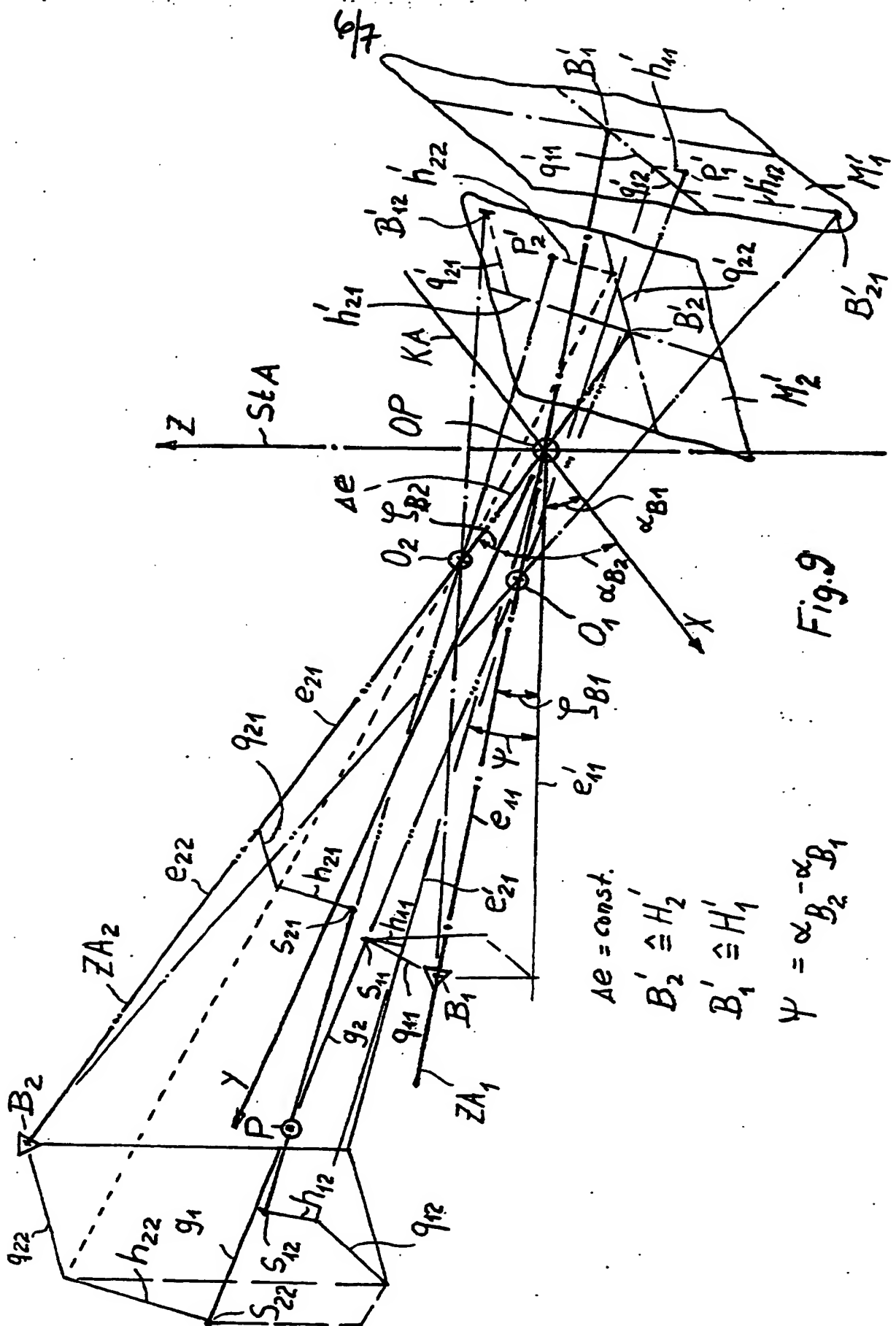


Fig.9

$$Ae = \text{const.}$$

$$B'_2 \cong H'_2$$

$$B'_1 \cong H'_1$$

$$\psi = \alpha_{B_2} - \alpha_{B_1}$$

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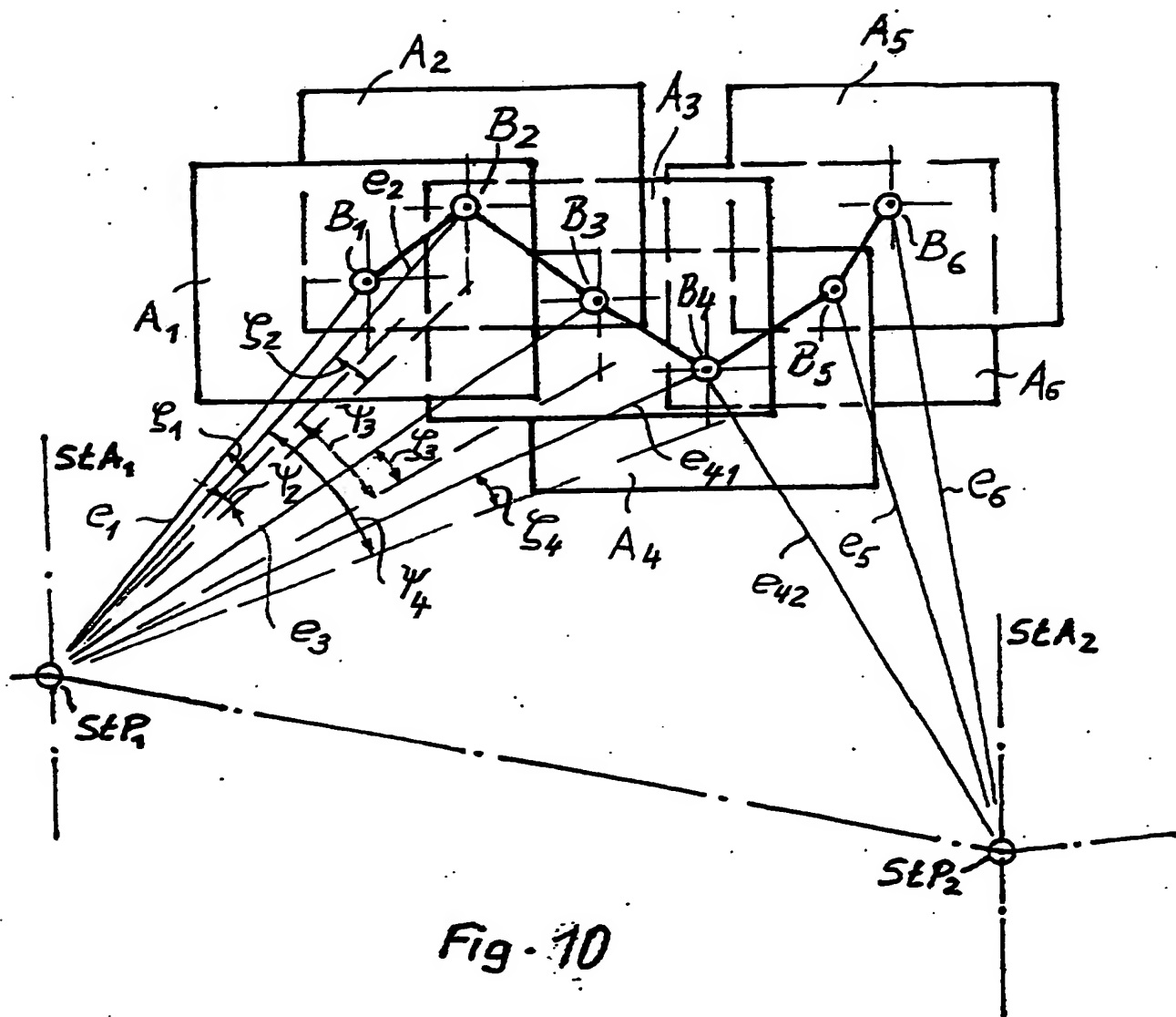


Fig. 10



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DESCRIPTION

METHOD AND AN ARRANGEMENT FOR DETERMINING THE SPATIAL  
COORDINATES OF AT LEAST ONE OBJECT-POINT

The invention relates to a method and an arrangement for determining the spatial coordinates of at least one object-point using video-image surveying-tachymetry, preferably for use in geodetic surveying and also in measuring buildings and objects.

Modern electronic tachymeters/tacheometers have at their disposal an arrangement for automatic precision target seeking. In the first step, the said tachymeters would render it possible, in the presence of image evaluating electronics, to store the target image for the purpose of supplementing the measurement data of the tachymeter which consists of the distance to the target point marked by a reflector, the horizontal angle and the vertical angle. This enables the entire surrounding area of the measurement point to be stored in the digital image. This would be the most simplest form of a video tachymeter. The prerequisite for this is that in the horizontal direction the object field or the object are almost vertical with respect to the optical axis of the video tachymeter and all objects appear sharply defined simultaneously in the target image. It is likewise necessary for the sighting to be almost horizontal.

DE 36 28 350 does disclose an arrangement of a "video tachymeter", wherein a video camera, which is arranged on a tachymeter, is used to photograph the reflector with a point number plate, in order to provide the measurement value of the tachymeter with additional information, i.e. the point number. In other words, additional information is collected which is merely used to provide improved documentation of the terrain points to be surveyed. It is not possible with this arrangement to survey the terrain points using the images recorded.

A likewise simple arrangement with a completely different task is illustrated in DE 198 00 336, wherein a sensor measuring unit is located on the camera to measure distances. In this arrangement, data is collected for orientating the camera to the object and used digitally. The measurement values of the camera thus receive absolute orientation.

WO 97/36147 likewise involves orientating a video camera to a scene, the object, with three selected points, whose position is known. Data from the recorded images is used to determine the position of the camera.

A completely different task is dealt with in DE 196 04 018. The arrangement comprises a theodolite with a target point pointer and a laser beam distance measuring device thereon to measure the distance without a reflector. In this case, the distance to the surface of the object is measured and the edges thereof are sighted using a telescope and the angular position

of the object is determined. The width of the object can be calculated from the distance and the angle. A video tachymeter is not used in this case. A computer is used to calculate measurement values of the object from the determined measurement data from the theodolite and distance measuring device. An image of the object to be measured is not recorded and measurement data of the object is not determined from this image.

EP 0 417 125 B1 (DE 689 04 911 T2) uses a similar arrangement via three points to determine the correlation of these three points with respect to the surfaces of areas by measuring distances and angles. If several surfaces are to be surveyed, then lines of intersection and corner points can be determined depending upon the number of the surveyed surfaces. Again, in this case, no images of the area to be surveyed are recorded, nor are images used to obtain measurement data.

Arrangements to measure distance and adjust focus on photographic equipment do not meet the high demands which geodetic surveying places on accuracy.

In the company information package "Surveyor™ ALS with Video Option" issued by the company MDL a digital video camera is used to compile a digital terrain image, of an object in the form of a terrain, from spatially orientated and positioned video-images and this terrain image is measured with the aid of polar data (distance and angle) which are determined in the same manner as with a normal tachymeter. This

digital terrain image comprises planimetry and altimetry information, the latter being determined, and subsequently represented, in the form of contour lines by way of a geometric calculation, as is conventional when producing plans and maps. It is then possible using this information to determine volumes and to produce terrain models. Since the information involves a distance measuring device which does not use a reflector, it is possible to survey open terrain from a high station without having physically to walk across the terrain. This is an advantageous optional application of video-tachymetry. Unfortunately, it is encumbered with an extremely low level of accuracy.

To summarize, it can be established that according to the prior art mentioned:

- no measurements are taken in the video image,
- the video image measurement data is not coupled with the data from the tachymeter and/or theodolites, such as distance, horizontal and vertical angle,
- no data is derived from this direct measurement data,
- and thus no video-tachymetry is performed.

The task of the EV resides in obtaining measurement data from the stored target image and to use said data to determine other object-points. For this purpose, several base points, which are marked by reflectors, are recorded in the video image, in addition to which subsequently distances and angles are measured centrally in order subsequently, during a

later in-house evaluation of the measurement data and measurement images, to determine from the measurement data of the video image measurement points between the marked base points. When great distances are involved, all images appear clearly defined almost simultaneously. Where the distances to the target are shorter and the objects extend in depth, in order to recognise the marked object-point in a clearly defined environment, transformation of the images of the base points to this image occurs with maximum contrast. Thus, it is possible to mark the desired object-point precisely. For this reason, the digital image must have the quality of a survey photograph. This option renders it possible, when photographing terrain, to concentrate on the important aspects which simultaneously form the base points to determine other object-points from the video-image during the in-house working phase, which object-points are obtained numerically in their position from the base points. These object-points can be marked both during the recording or also afterwards in the video-image by clicking the mouse. This option saves time during outside recordings and renders it possible to add to the recording made on site without having to return to the scene and without additionally inspecting the field.

It follows from this, that the object of the invention is to produce a method and an arrangement for video-image surveying-tachymetry which can be used to obtain from the recorded target image measurement data

to determine effectively the position of object-points and which also renders it possible to reduce the expenditure during geodetic surveys.

In accordance with the invention this object of the invention is achieved using a method according to the first claim, wherein claims 2 to 7 describe the further embodiment of the method and details of the method steps. The arrangement which can be used to implement the method is illustrated in claim 8 and the following subordinate claims describe more detailed embodiments and details relating to the arrangement.

Thus, it is advantageous if the tachymetrically determined base points are marked in the recorded target images.

In order to facilitate the measuring of object-points and to reduce the work outside in the field, the object-points  $P_i$  at the target point to be measured are advantageously selected in a target image transmitted to a screen provided there or subsequently during the in-house processing using recorded and stored target images.

It is advantageous in the case of a method for determining the spatial coordinates of at least one object-point  $P_i$  from the coordinates of at least two base points which serve as reference points and which are determined with the aid of a video tachymeter which is disposed in a recording station, can pivot about a perpendicular vertical axis  $StA$  and is provided with a recording, which can tilt about a horizontal tilt axis, for a distance measuring device, with a video camera

having a CCD matrix, with a sighting device and with angle measuring devices, to provide the following method steps:

- Sighting two base points lying in the object space and by means of the video tachymeter which is disposed in a recording station and can pivot about a vertical axis by a horizontal angle and which comprises a video camera which can tilt about the horizontal tilt axis by a vertical angle and determining the oblique distances to the at least two base points with the aid of the distance measuring arrangement of the video tachymeter,
- Producing two video images containing in each case at least two base points and storing said images, whereby the camera is aligned in each case in such a manner that the image of the respective sighted base point lies in the respective main point of the lens of the video camera,
- With the aid of the target image coordinates, measured in the target images, of the object-point imaged on the CCD matrix of the video camera, selected and lying in the object space, and from the oblique distances to the base points, from the measured horizontal angle, from the vertical angles to the base points, from a device constant and from the focal length of the lens of the video camera, determining the coordinates  $x$ ,  $y$  and  $z$  at least of one desired object-point, which lies in the space recorded by the video images and is marked during the recording or on the recorded

video images, wherein these coordinates  $x$ ,  $y$  and  $z$  are co-ordinates of a co-ordinate system having the axes  $X$ ;  $Y$ ;  $Z$  with the origin of their coordinates lying in the point of intersection of the tilt axis and vertical axis of the video tachymeter and the vertical axis stands perpendicularly on the  $X$ - $Y$  plane and fixes the direction of the  $Z$  axis.

It is advantageous if the method is performed in the following method steps:

- a. Sight a first base point by adjusting the axis of the video camera below a first horizontal angle and below a first vertical angle with respect to the  $X$ - $Y$  plane in the direction of the first base point and measure the first vertical angle and the first horizontal angle, wherein the vertex of this vertical angle and of the horizontal angle lies in the tilt axis of the video tachymeter, record and store a first target image and measure the oblique distance to this first base point using a distance measuring arrangement which is disposed in a coaxial manner with respect to the axis of the video camera of the video tachymeter, wherein the video camera is aligned in such a manner that the image of the first base point lies in the main point of the lens of the video camera and moreover contains the image of the second base point.
- b. Pivot the video tachymeter by a second horizontal angle formed by means of the two base points and the vertical axis of the video tachymeter, wherein



the vertex of this angle lies on the site of the vertical axis;

- c. Sight a second base point by adjusting the axis of the video camera below a second horizontal angle and below a second vertical angle with respect to the X-Y plane in the direction of the second base point and measure the second vertical angle and the second horizontal angle, wherein the vertex of this angle lies in the tilt axis of the tachymeter, record and store a second measurement image and measure the oblique distance to this second base point using the distance measuring device of the video tachymeter, wherein the video camera is aligned in such a manner that the image of the second base point lies in the main point of the lens of the video camera and moreover contains the image of the first base point.
- d. Determine the coordinates of any object-points contained in the recorded target images and lying in the object space with the aid of the coordinates of the first and of the second base points by means of:
  - da Marking the desired object-point during the recording in the video image produced in each case or  
Marking the desired object-point in the recorded video images by clicking the mouse,
  - db Measuring the target image coordinates of the object-point in the recorded video images or photographs,

- dc    Converting the target image coordinates of the object-point lying in the respective plane of the CCD matrix into analogue coordinates lying in the object space with the aid of:
- the measured oblique distances to the two base points, corrected using the device constant,
  - the measured target image coordinates,
  - the focal length of the lens of the video camera,
- dd    Calculating the parameters of the required support points with the aid of:
- image coordinates of the target images converted into the object space
  - the measured oblique distances to the two base points,
  - the measured horizontal angle, by which the video tachymeter must be pivoted about the vertical axis when sighting the base points in succession,
  - the measured said vertical angles with respect to the base points,
  - distances which are derived from the horizontal angle, from the said oblique distances and the two vertical angles,
- de    Transforming these support point parameters into the coordinates of the coordinate systems X; Y; Z with its origin in the point of intersection of the vertical axis and the

tilt axis and determining the coordinates of these support points in this coordinate system.

- e Calculate the coordinates  $x$  ;  $y$  and  $z$  of the object-point with the origin of the coordinates of the said coordinate system, which origin lies in the point of intersection of the tilt axis and vertical axis of the video tachymeter, with the aid of the coordinates of the said support points by determining the coordinates of the point of intersection of two straight lines  $g_1$  and  $g_2$  which are defined by these support points. The coordinates of this point of intersection are also the coordinates of the object-point to be surveyed.

In order to continue a video-image traverse commenced in a first station of the tachymeter with a survey traverse consisting of the object-points from a second tachymeter station, the survey traverse which consists of object-points and is to be continued by the second station of the tachymeter is determined by the first station of the tachymeter.

In accordance with a further embodiment of the method in accordance with the invention it is particularly advantageous, when the additional object-point lies in a different focal plane, as can rapidly occur in the case of close range targets and the observer must refocus to this plane and clearly mark the desired object-point, if an image evaluating device determines the target image coordinates of the desired

object-point and associated with any object-point plane, once an auto-focussing device has focussed on the target image planes of the object-points. The image evaluating device for recognising object-points and specifying them as the object-point with a specific position is performed therefore by virtue of a transformation from known target image planes to such a plane with maximum contrast.

An arrangement for determining the spatial coordinates at least of one object-point comprises in the measuring station an electronic tachymeter having an automatic sighting unit and a transmitter and in the sighting point a sighting rod with a reflector, receiver and the graphic field book with storage components. The electronic tachymeter or video tachymeter can pivot about a vertical axis and comprises a distance measuring device which can tilt about a tilt axis and a video camera having a CCD matrix. Moreover, the video tachymeter comprises a sighting device and angle measuring devices for measuring horizontal and vertical angles. It is advantageous, if at least one part of the ray path of the distance measuring arrangement is disposed in a coaxial manner with respect to the optical axis of the video camera, if for the purpose of focussing the CCD matrix of the video camera there is provided a focussing arrangement which can be controlled in dependence upon the distance measured by the distance measuring arrangement or can be controlled manually depending upon the sharpness of the video image and if

an image processing system is provided for recognising object-points and their specification as an object-point with a predetermined position.

In an advantageous manner the CCD matrix of the video camera is disposed for focussing purposes in a tube which can be displaced in a controlled manner in the direction of the optical axis and which is displaced by means of a drive computer-controlled according to an algorithm.

It is thus further advantageous that the respective displacement path of the CCD matrix is calculated by the computer according to the distances to the respective sighted base points determined by the distance measuring arrangement.

It is of further advantage if an imaging evaluating device controls an automatic focussing arrangement such that the focussing adjustment of the CCD matrix and associated with any object plane measures the target image coordinates of the desired object-point  $P_1$ , wherein the base points  $B_1$  and  $B_2$ , whose images  $B'_1$  and  $B'_2$  lie in the target image planes  $M'_1$  and  $M'_2$ , must be sighted.

When focussing the CCD matrix, the displacement path can also be derived by means of an image transformation according to maximum, to an object-point plane lying between the target image planes of the base points.

In order to be able to perform all the operations both in the target point and in the station, the sighting rod lying in the target point comprises a signal or data receiver and a computer with a target

screen.

The method includes the progressive marking of the measuring points in the target images in the target point, the controlling of the measurement process and the method of determining the selected object-points from the measurement data of the tachymeter and its camera. The determination of the object-points in their position in all three coordinates from two measuring points is possible in accordance with the invention only by virtue of the fact that additional support points are derived from the tachymeter data and the video image data, so that it is possible to form from this intersecting straight lines whose points of intersection then represent the selected object-points with their coordinates. The tachymetric reference points can also be marked using a laser pointer and the distances can be measured without the use of a reflector. The horizontal and vertical angles are given in the known manner with the sighting. The marked reference or base points are emphasised by the laser light in the video image. The allocation of the images is also provided by the given angle.

The invention is further explained hereinunder with reference to an exemplified embodiment and associated drawing, in which:

Figure 1 shows a simplified illustration of the position of the base points and object-points with respect to an optical telescope,

Figure 2 shows the field of vision of the optical

telescope,

Figure 3 shows a simplified illustration of the position of the base and object-points with respect to a CCD camera with a screen,

Figure 4 shows the image on the screen of the CCD camera,

Figure 5 shows an arrangement in accordance with the invention for determining the spatial coordinates of object-points,

Figure 5a shows a front view of a sighting rod at the target point,

Figure 6 shows a simplified illustration of a video tachymeter,

Figure 7 shows the geometric connections when sighting two base points and determining the coordinates  $X$  and  $Y$  of an object-point in the  $X$ - $Y$  plane,

Figure 8 shows the geometric connections when sighting two base points and the determination of the coordinates of an object-point in the case of close range targets,

Figure 9 shows a schematic illustration of the determination of the spatial coordinates  $x$ ,  $y$  and  $z$  of an object-point  $P_i$  related to a tachymeter station and

Figure 10 shows a video survey traverse for measuring rows of object-points.

For the sake of simplicity Figure 1 illustrates an optical telescope 1 of a tachymeter with a lens 2 and an ocular 3. The base points  $B_1$  and  $B_2$ , whose coordinates  $x$ ,  $y$  and  $z$ , are known lie at a distance from the telescope 1, for example, in the terrain.  $P_1$  and  $P_2$  denotes the object-points whose coordinates are to be determined in accordance with the method according to the invention with the aid of the base points  $B_1$  and  $B_2$ . The telescope 1 can pivot about an axis  $StA$  so that the base points  $B_1$  and  $B_2$  can be sighted one after the other. These base points and object-points are imaged in a known manner in the ocular image plane 4 of the telescope 1.

Figure 2 illustrates the field of vision 5 which is visible in the ocular image plane 4 of the optical telescope 1 with the position of the images of the base points  $B'_1$  and  $B'_2$  and the images of the object-points  $P'_1$  and  $P'_2$ .  $X$ ,  $Y$  and  $Z$  denote the coordinate axes.

Figure 3 illustrates a video camera 6 with a lens 7 in whose image plane 8 is disposed a CCD matrix 9 consisting of CCD elements, on which the terrain is imaged with the base points and the object-points. The image field imaged on the CCD matrix 9 with the images of the base and object-points  $B'_1$ ,  $B'_2$ ,  $P'_1$  and  $P'_2$  are visible for the observer on a screen 10 of the video camera 6.

Figure 4 illustrates on the screen 10 of the video camera 6 the position of the images  $B'_1$ ,  $B'_2$ ,  $P'_1$  and  $P'_2$  of the imaged base points  $B_1$  and  $B_2$  and of the object-points  $P_1$  and  $P_2$ .  $X$ ,  $Y$  and  $Z$  also denote the coordinate axes. For the sake of simplicity and to provide a better overview of the conditions, the base and object-points also lie in the



X-Y plane as in Figure 2. The video camera 6 can pivot about an axis StA in order to be able to align it with the base points  $B_1$  and  $B_2$  one after the other. The observer can target the base point  $B_1$  with the middle M of the apparent cross-lines and mark it with the cursor C in order, if the position of the base point  $B_2$  is also known, to determine numerically the position, for example, of the object-point  $P_1$ .

Figure 5 illustrates an arrangement for determining the spatial coordinates of object-points, which comprises in the measuring station an electronic or video tachymeter 11 with a levelling base 12 on a stand 13, the tachymeter 11 with its axis (vertical axis) StA being centred according to the vertical sighting axis 14 above a base point 15. The video tachymeter 11 is adjusted for level by means of screws on the levelling base 12 using a circular level 16 and comprises the video camera 6 with a coarse sight 17. For the purpose of sighting the target point, the video camera 8 can be tilted about a tilt axis and the entire tachymeter 11 can be rotated about the axis StA by means of a button 18 which is located on the telescope. Furthermore, the video tachymeter is provided with a transmitter which has an antenna 19 and a sighting device. As is evident from Figure 5, a display 20, which displays the target point, is located on the upper part of the tachymeter 11. Moreover, the image centre is marked on the display 20 by means of cross lines. The precise sight adjustment can be performed by the observer using the horizontal focussing adjustment and the vertical focussing adjustment of the tachymeter 11.

Disposed in the target point above a base point 22 is a sighting rod 21 on which is arranged a circular level 23, for aligning the said sighting rod in the vertical direction, and also a reflector carrier 24 which supports the reflector 25 in such a manner that it can tilt. Furthermore, the sighting rod carries a battery 26, a video display 27, a control unit 28 with its own screen and a radio device 29 (Fig. 5a) with antenna 30. In order to align the sighting rod 21 with the video tachymeter 11 located in the measuring station in the centre of the ground point 22, the rod is aligned by hand vertically using the circular level 23, the sighting rod 21 is then rotated and the reflector 25 tilted until it has sighted the video tachymeter 11 in the measuring station. As a consequence, the tachymeter 11 can also sight with its sighting axis ZA the reflector 25 on the sighting rod 21. The radio distance performs the image and data transmission between the measuring station and the target point on command. With the aid of a joystick the observer uses a cursor [not illustrated] in the target image appearing on the video display 27 to determine the above mentioned object-points numerically and to mark them, if he/she has previously determined the base points necessary for the determining process, as has been illustrated in Figures 4 and 5.

Figure 5a illustrates a frontal view of the sighting rod 21 mentioned in Figure 5 with its units disposed thereon, the same designations having been used for parts which are identical to those in Figure 5.

Figure 6 illustrates the plan view of the structure of

the video tachymeter 11. The levelling base 12 carries the supports 31 with an operating panel 32, a camera body 33 of the video camera 6 and the display 20. A coarse sight 17 comprising an ocular 34, with an exit pupil 35 lying far outside, and a height adjustment device 36 is located on the camera body 33. The camera body 33 carries the video camera 6 comprising the lens 7 with the front nodal point K and the CCD matrix 9 in the image plane, the said video camera being attached to a mother board 9.1 and disposed centrally with respect to the tube 6.1 of the camera 6. For focussing purposes, this tube 6.1 is positioned in a cylindrical sleeve 6.2 with a small amount of clearance. It is controlled via an entrainer 37 whose nut 37.1 is positioned concentrically on a threaded shaft 37.2, via a drive 38 by the motor 39 according to an algorithm of a computer.

The computer is located advantageously on a printed circuit board 40 and is not illustrated in Figure 6. The threaded shaft 37.2 is positioned in the bearing 37.3 and is connected to the transmission 38. The computer uses a generally known programme to calculate the displacement path of the CCD matrix 9 according to the distances to the respectively sighted base point B which lies in the terrain, the said distances having been determined by the distance measuring device 41 of the video tachymeter 11.

The axis of the distance measuring device 41 lies concentric to the axis KA of the video camera 6, this axis being formed by the front nodal point K and the main point H in the centre of the CCD matrix 9. This axis lies in the centre of the ray bundle of the distance measuring device

41, the ray bundle consisting in the known manner of the two half-bundles, a transmitter- and a receiver-bundle.

This axis extends from the nodal point K of the lens 7, which is disposed in the lens holder 42, to a selective mirror 43. The receiver-bundle passes through the lens, is reflected on the selective mirror 43 and guided via the deflecting prisms 44 and 45 and via an intermediate image plane 46 into the distance measuring device 41.

A visible transmitter bundle, which is emitted by a laser 48 via a prism 47, is projected into the space via the lens 7 and via the inner reflection surface of the prism 44 which is disposed centrally with respect to the lens 7. The said transmitter bundle serves as a ray bundle which lies centrally with respect to the camera axis KA, *inter alia*, for the purpose of marking physical objects or for directing rays from reflectors into terrain, which, for example, can represent object-points which are to be measured. These object-points P marked in this manner are shown on the CCD matrix 9 as measuring points.

Furthermore, a handle 49 for tilting the video camera 6 about the axis KA and for rotating the entire tachymeter 11 by hand about the axis StA is also located on the video tachymeter 11. Similarly, the handle 49 can also be used to focus the video camera 6 coarsely and thus to focus the image on the display 20. As is the case with any tachymeter, the tilt axis KA and the vertical axis StA of the video camera 6 also intersect each other in a point of intersection, the vertical axis StA also being the optical axis of the camera. The figures do not illustrate the components and the mechanical and electronic functional

units which are at the disposal of every electronic or video tachymeter, such as angle measuring devices and inclinometers, adjusting elements for sighting, current supply and device control and data storage. They form part of the prior art.

In the method for determining the spatial coordinates of at least one object-point  $P_i$  from the coordinates  $x$ ,  $y$  and  $z$  of at least two base points  $B_i$ , which serve as reference points and do not lie in one plane, with the aid of a video tachymeter 11 which is disposed in a recording station, can pivot about the perpendicular vertical axis  $StA$  and comprises a distance measuring arrangement, which is formed as a distance measuring device 41, and a video camera 6 having a CCD matrix 9, a sighting unit and angle measuring devices, wherein the video camera 6 can be tilted about a horizontal axis, a tilt axis  $KA$ , the coordinates  $x$ ;  $y$  and  $z$  of any object-points  $P_i$  are derived from base points  $B_i$  in the terrain which are measured and marked in each case by means of a reflector, laser spot, etc. In addition, a target image, which contains the marked base points  $B_i$  and the object-points  $P_i$ , is recorded and stored. The coordinates of any object-points  $P_i$  are then determined from the position data (coordinates) in the target images which are contained in the target images of the marked base points  $B_i$  which have been determined using the tachymeter. The base points  $P_i$  which have been determined using the tachymeter are marked in the recorded target images, for example, by clicking the mouse or in a different suitable manner.

The object-points  $P_i$  to be surveyed can also be

selected at the target point in a target image transmitted to a screen or video display 27 (Figure 5) provided at this site, or later during the in-house processing.

Figure 7 shows by way of example the schematic illustration of the process of determining the coordinates  $x$  and  $y$  of an object-point  $P$  with the aid of two base points  $B_1$  and  $B_2$ , wherein all these points lie in the horizontal  $X$ - $Y$  plane. The video tachymeter 11, whose lens  $O$  is represented in two positions  $O_1$  and  $O_2$  which are set one after the other and are illustrated in Figure 7, stands in a recording station which is designated by  $StA$  in Figure 7 as the intersection point of the vertical axis of the video tachymeter through the  $X$ - $Y$  plane and simultaneously represents the zero point  $OP$  of the coordinates system with the coordinate axes  $X$  and  $Y$ . Using the distance measuring device [not illustrated] of the video tachymeter, whose measuring axis extends in a first position coaxially with the axis  $O_1B'_1$  of the video camera, the horizontal distance  $e_{11}$  to the sighted base point  $B_1$  is measured, the image  $B'_1$  of the base point  $B_1$  lying in the main point  $H'_1$  on the plane  $M_1$  of the CCD matrix of the video camera.

Subsequently, the base point  $B_2$  is sighted in a similar manner to that described regarding  $B_1$ , by pivoting the CCD camera about the axis  $StA$  in such a manner that the camera axis  $O_1B'_2$  is aligned to the base point  $B_2$  and the target image plane is brought into focus accordingly, so that a sharp image is produced. The image  $B'_2$  of the base point  $B_2$  occurs in the plane  $M'_2$  of the CCD matrix. Simultaneously, the horizontal angle  $\psi$  is measured with the horizontal circle of the video tachymeter and the

horizontal distance  $e_{22}$  to the base point  $B_2$  is measured with the distance measuring device of the video tachymeter. The target images  $M'_1$  and  $M'_2$ , obtained in this manner with respect to the two base points  $B_1$  and  $B_2$  are stored.

When sighting the base points  $B_1$  and  $B_2$ , attention must naturally be given to the fact that the object-point  $P$  or, if there are several, the object-points  $P_i$  are also imaged on these target images  $M'_1$  and  $M'_2$ .

The coordinates of an object-point  $P_i$  in the X-Y plane are determined using the two base points  $B_1$  and  $B_2$  as follows (Figure 7):

It is possible either during the recording to mark in the existing video image the desired object-point  $P$  on the screen and then immediately following this to measure the image coordinates  $p'_{11}$  and  $p'_{12}$  of the image points  $P'_{11}$  and  $P'_{12}$  in the plane  $M'_1$  or  $M'_2$  of the CCD matrix 9, the reason being that the object-point  $P$  which has been recognised and marked in one image is, owing to its structuring, also measured and marked in the preceding image by virtue of the image recognition algorithm, or it is possible at a later stage to use the images on the screen and to mark the desired object-point  $P$  by clicking the mouse in the overlapping video and calculate the coordinates using the computer, wherein the coordinates are calculated according to the following formulae with the aid of the computer, wherein the variables quoted in the formulae further explained below are illustrated in Figure 7.

Thus, from the measured horizontal distances  $e_{11}$  and  $e_{22}$ , the measured horizontal angle  $\psi$ , the constants  $\Delta e_1 = \Delta e_2 = \Delta e$  and the image coordinates  $p'_{11}$  and  $p'_{12}$  of the

image points  $P'_{11}$  and  $P'_{12}$  in the plane  $M'_1$  or  $M'_2$  of the CCD matrix 9 the rising heights  $p_{11}$ ,  $p_{12}$ ,  $p_{21}$  and  $p_{22}$  in the object space are calculated according to laws of similarity, wherein the constant  $\Delta E$  is the distance of the vertical axis StA from the main point  $O = O_1 = O_2$  of the lens  $O_1$  and  $O_2$  are the different positions of the lens of the video camera. For this purpose, additional distances  $e_{12} = e_{11} \cdot \cos \psi$  and  $e_{21} = e_{22} \cdot \cos \psi$  are derived from the measured values determined for the horizontal distances  $e_{11}$  and  $e_{22}$  and the horizontal angle  $\psi$ . In conjunction with the explanations below relating to Figure 8, the designation "oblique distance" is used for the variables  $e_{11}$  and  $e_{22}$  in order to differentiate, because in this case points lying in the space are sighted.

The horizontal distances  $e_{11}$  and  $e_{22}$ , the said additional distances  $e_{12}$  and  $e_{21}$ , the measured horizontal angle  $\psi$  and the calculated rising heights  $p_{11}$ ,  $p_{12}$ ,  $p_{21}$  and  $p_{22}$  are then used to determine the right-angled coordinates of four support points  $S_{11}$ ,  $S_{12}$ ,  $S_{21}$  and  $S_{22}$  in the coordinate system of the video tachymeter 11 related to the first base point OP. The support points  $S_{11}$  and  $S_{12}$  define a straight line  $g_1$  and the support points  $S_{21}$  and  $S_{22}$  define a straight line  $g_2$ . These straight lines  $g_1$  and  $g_2$  are calculated according to known mathematical formulae. The point of intersection of these two straight lines  $g_1$  and  $g_2$  is the desired object-point P with its coordinates x and y in the coordinate system of the video tachymeter 11 whose origin lies in the vertical axis StA in the point OP.



The rising heights  $p_{11}$ ,  $p_{12}$ ,  $p_{21}$  and  $p_{22}$  and the coordinates of the support points  $S_{11}$ ,  $S_{12}$ ,  $S_{21}$  and  $S_{22}$  are calculated according to the following formulae, where  $f$  represents the focal length of the lens:

Rising heights:

$$p_{11} = p'_{11} / f (e_{11} - \Delta e)$$

$$p_{12} = p'_{11} / f (e_{22} \cos \psi - \Delta e)$$

$$p_{22} = p'_{12} / f (e_{22} - \Delta e)$$

$$p_{21} = p'_{12} / f (e_{11} \cos \psi - \Delta e).$$

Coordinates of the support points:

$$\begin{array}{ll} S_{11} : x = p_{11}, & y = e_{11} \\ S_{12} : x = p_{12}, & y = e_{22} \cos \psi \\ S_{22} : x = e_{22} \sin \psi - p_{12} \cos \psi, & y = e_{22} \cos \psi + p_{22} \sin \psi \\ S_{21} : x = e_{11} \sin \psi \cos \psi - p_{21} \cos \psi, & y = e_{11} \cos^2 \psi + p_{21} \sin \psi \end{array}$$

It is advantageous for a high degree of accuracy in determining the coordinates of the desired object-point  $P$ , if the base points  $B_1$  and  $B_2$  are spaced as far apart as possible. The object-point  $P$  and the object-points  $P_1$  should not lie so close or behind the base points  $B_1$  and  $B_2$ . However, the object-points can easily lie in the intermediate space in front of or behind the base points  $B_1$  and  $B_2$ .

Figure 8 describes the geometric relations when sighting two base points  $B_1$  and  $B_2$  and the process of determining the coordinates  $x$  and  $y$  of at least one object-

point P in the X-Y plane in the case of close range targets. The target distances involved are considered to be those up to approx. 100 m.

If the base points  $B_1$  and  $B_2$  and the at least one object-point P lie in different spaced intervals from the vertical axis of the video tachymeter when the distances to the target or the focussing distance are short, then it is necessary to bring the individual points into focus for each distance, which applies both for the base points  $B_1$  and  $B_2$  and also for the one or several object-points, from which the coordinates are determined.

The two base points  $B_1$  and  $B_2$  are first measured and the distances  $e_{11}$  and  $e_{22}$  and the angles  $\alpha_{B_1}$  and  $\alpha_{B_2}$ , which lie in the horizontal plane, are determined. If the object-point P (Figure 8) is now to be measured, then the base point  $B_1$  is sighted and clearly defined, i.e. brought into focus, and during this sighting process P is brought into focus in the target plane  $M_{P_1}$  and the image P' of the object-point P is marked in the image, so that the image coordinate  $p'_1$  can be measured in the image in the place  $M'_{P_1}$ .

Following on from this, the second base point  $B_2$  is sighted and defined clearly in the image plane. The focus is then changed to the target plane  $M_{P_2}$  from P. The object-point P is still marked in this plane and has the same image distance  $b_{p_2} = b_{p_1}$ , as in the method step described in the previous paragraph, which is measured simultaneously by the automatic focussing device. Moreover, the image coordinates  $p'_2$  are measured in target plane  $M_{P_2}$ . These image coordinates  $p'_1$  and  $p'_2$  as well as

the image distance  $b_{p1}$  are then used to calculate the rising heights  $p_{11}$ ;  $p_{12}$ ;  $p_{21}$  and  $p_{22}$  according to the relations described further above in connection with the description of Figure 7, wherein the focal length  $f$  is replaced in the relations by the image distance  $b_{p2} = b_{p1}$ , because the image distances are no longer in the focal plane, as is the case where the distances to the target are great, but rather lie in the image distance  $b_{p1}$ . Again,  $S_{11}$ ;  $S_{12}$ ;  $S_{21}$  and  $S_{22}$  are also support points which fix the straight lines  $g_1$  and  $g_2$ , whose intersection point coordinates are the coordinates of the object-point  $P$ . The same algorithm is therefore used to determine the coordinates of the object-point  $P$  as is used to determine the coordinates of far-range object-points (seen optically at an infinite distance).

Referring to Figure 9 and taking into consideration the designations used for the individual components and elements in Figure 6, the method represented in the patent claims 4 and 5 for determining the spatial coordinates  $X$ ;  $Y$  and  $Z$  of an object-point with the aid of at least two base points  $B_1$  and  $B_2$ , which serve as reference points, in relation to the tachymeter station (vertical axis  $StA$ ) is further explained and described. The first to be determined are the coordinates of the base points  $B_1$  and  $B_2$  lying in the object-point planes  $M1$  and  $M2$  with the aid of a video tachymeter 11 which is disposed in a recording station  $OP$ , can pivot about a perpendicular vertical axis  $StA$  and is provided with a recording, which can tilt about a horizontal tilt axis  $KA$ , for a distance measuring device 41, with a video camera 6 having a CCD matrix 9, with a

sighting device and with angle measuring devices (not illustrated) (Figure 6).

Next, the following method steps are performed to determine the coordinates of the object-point  $P$  to be measured:

In a first step, the two base points  $B_1$  and  $B_2$  lying in the object space are sighted using the video tachymeter 11 which is disposed in the recording station  $OP$  and can rotate about the vertical axis  $StA$  by a horizontal angle  $\psi$  (Figure 6) and which comprises a video camera 6 which can tilt about the horizontal tilt axis  $KA$  by the vertical angle  $\xi_1$  and  $\xi_2$  and the oblique distances  $e_{11}$  and  $e_{22}$  to the at least two base points  $B_1$  and  $B_2$  are determined with the aid of the distance measuring device 41 of the video tachymeter 11 and two video images containing the at least two base points  $B_1$  and  $B_2$  are produced and stored, wherein the camera 6 is aligned in each case so that the images  $B'_1$  or  $B'_2$  of the respective sighted base points  $B_1$  or  $B_2$  lie on the optical axis in the respective main point  $H'_1$  or  $H'_2$  on the CCD matrix 9.  $O_1$  and  $O_2$  denote the two positions of the lens of the video camera when sighting the two base points  $B_1$  and  $B_2$ .

The next to be determined are the coordinates  $x$ ,  $y$  and  $z$  of at least one desired object-point  $P_1$  ( $P$ ), which lies in the space recorded by the video images or on the CCD matrix 9, and is selected and marked during the recording or on the recorded video images with the aid of the target image coordinates  $q'_{11}$ ;  $q'_{12}$ ;  $h'_{11}$ ;  $h'_{12}$  of the selected object-point  $P$  ( $P_1$ ) lying in the object space and imaged on the CCD matrix 9, from the oblique distances  $e_{11}$  and  $e_{22}$ ,

the measured horizontal angle  $\psi$  in the horizontal plane between the base points  $B_1$  and  $B_2$ , the vertical angles  $\xi_{B1}$  and  $\xi_{B2}$  from the horizontal plane to the base points  $B_1$  and  $B_2$ , the device constants  $\Delta e$  and the focal length  $f$  of the lens of the video camera 6, wherein these coordinates  $x$ ,  $y$  and  $z$  are coordinates of a coordinate system with the axes  $X$ ;  $Y$ ;  $Z$  with their coordinate origin  $OP$  lying in the point of intersection of the tilt axis  $KA$  and the vertical axis  $StA$  of the video tachymeter 11 and the vertical axis  $StA$  stands perpendicular to the  $X$ - $Y$  plane and fixes the direction of the  $Z$  axis, wherein  $I = 1; 2; \dots; n$  represents a natural number which refers to the respective allocated object-point.

In detail, the method steps involved are now explained further:

Firstly, the first base point  $B_1$  is sighted in the manner explained in connection with Figure 7 and the first target image  $M'_1$  is recorded and stored and the oblique distance  $e_{11}$  to this first base point  $B_1$  is measured using the distance measuring device 41 of the video tachymeter disposed coaxially with the axis of the video camera 6, wherein the video camera 6 is aligned so that the image  $B'_{21}$  of the base point  $B_1$  lies on the optical axis (target axis  $ZA_1$ ) in the main point  $H'_1$  of the video camera and moreover contains the image  $B'_2$  of the second base point  $B_2$ . The oblique distance  $e_{11}$  is the distance between the origin  $OP$  of the coordinates and the base point  $B_1$ . Also, as the axis  $ZA_1$  of the video camera is adjusted, the vertical angle  $\xi_{B1}$  to the first base point  $B_1$  is measured with respect to the  $X$ - $Y$  plane, wherein the vertex of the angle

in the tilt axis KA lies in the point OP.

The video tachymeter 11 is then pivoted by a horizontal angle  $\psi$  which is formed by the two base points  $B_1$  and  $B_2$  and the vertical axis StA and this angle is measured, wherein the vertex of this angle lies at the site of the vertical axis StA in the origin OP of the coordinates.

During the now following sighting of a second base point  $B_2$  and the recording and storing of a second target image  $M'_2$  and the measuring of the oblique distance  $e_{22}$  to this second base point  $B_2$  using the distance measuring device 41 of the video tachymeter, wherein the video camera 6 is aligned in such a manner that the image  $B'_2$  of the base point  $B_2$  lies on the optical axis in the main point  $H'_2$  of the video camera, it is guaranteed that, furthermore, the image  $B'_{12}$  of the first base point  $B_1$  is contained in the target image  $M'_2$ . The oblique distance  $e_{22}$  is the distance between the origin OP of the coordinates and the base point  $B_2$ . As the axis  $ZA_2$  of the video camera is adjusted, the vertical angle  $\xi_{B2}$  to the second base point  $B_2$  is measured with respect to the X-Y plane, wherein the vertex of this angle in the tilt axis KA lies in the origin OP of the coordinates.

After the two target images  $M'_1$  and  $M'_2$  have been recorded and stored, the coordinates are determined of any object-points  $P_i$  lying in the space and imaged in the recorded target images with the aid of the coordinates of the two base points  $B_1$  and  $B_2$ , wherein one object-point P is selected for the purpose of explanation with reference to Figure 8. The desired object-point P can be marked

either during the recording in the respective video image produced or in the recorded and stored target images by clicking the mouse. These recorded video images or target images  $M'_1$  and  $M'_2$  are used to determine the target image coordinates  $q'_{11}$ ;  $q'_{12}$ ,  $h'_{11}$ ;  $h'_{12}$  of the object-point  $P$  in each of the target images  $M'_1$  and  $M'_2$ . The target image coordinates  $q'_{11}$ ;  $q'_{12}$ ,  $h'_{11}$ ;  $h'_{12}$  of the object-point  $P$  lying in the plane of the CCD matrix 9 of the video camera are converted into the analogue coordinates  $q_{11}$ ;  $q_{12}$  and  $h_{11}$ ;  $h_{12}$  lying into the object space with the aid of the measured oblique distances  $e_{11}$  and  $e_{22}$ , corrected using the device constants  $\Delta e$ , the measured target image coordinates  $q'_{11}$ ;  $q'_{12}$  and  $h'_{11}$ ;  $h'_{12}$  and the focal length  $f$  of the lens of the video camera, wherein the indices 1 and 2 are used, if two base points  $B_1$  and  $B_2$  are available.

With the aid of the image coordinates  $q'_{11}$ ;  $q'_{12}$ ,  $h'_{11}$ ;  $h'_{12}$ , the measured oblique distances  $e_{11}$  and  $e_{22}$ , the horizontal angle  $\psi$  measured with the angle measuring systems of the video tachymeter and the vertical angles  $\xi_{B1}$  and  $\xi_{B2}$  likewise measured using the angle measuring systems of the video tachymeter, and also with the aid of distances  $e_{12}$  and  $e_{21}$  derived from the horizontal angle  $\psi$ , from the oblique distances  $e_{11}$  and  $e_{22}$  and the vertical angles  $\xi_{B1}$  and  $\xi_{B2}$  (Figure 8), the parameters  $q_{11}$ ;  $q_{12}$ ;  $h_{11}$ ;  $h_{12}$ ;  $h_{21}$ ;  $q_{21}$ ;  $h_{22}$ ;  $q_{22}$  of the support points  $S_{11}$ ;  $S_{12}$ ;  $S_{21}$ ;  $S_{22}$  lying in the object space are now calculated and from these the coordinates of the support points are calculated according to the relations below:

$$x_{s11} = e_{11} \cos \xi_{B1} \cos \alpha_{B1} - q_{11} \cos \alpha_{B1} + h_{11} \sin \xi_{B1} \sin \alpha_{B1}$$

$$y_{s11} = e_{11} \cos \xi_{B1} \sin \alpha_{B1} + q_{11} \sin \alpha_{B1} - h_{11} \sin \xi_{B1} \cos \alpha_{B1}$$

$$z_{s11} = e_{11} \sin \xi_{B1} + h_{11} \cos \xi_{B1}$$

$$x_{s12} = e_{22} \cos \xi_{B1} \cos \psi \cos \alpha_{B1} - q_{12} \cos \alpha_{B1} + h_{12} \sin \xi_{B1} \sin \alpha_{B1}$$

$$y_{s12} = e_{22} \cos \xi_{B2} \cos \psi \sin \alpha_{B1} + q_{12} \sin \alpha_{B1} - h_{12} \sin \xi_{B1} \cos \alpha_{B1}$$

$$z_{s12} = e_{22} \cos \xi_{B2} \cos \psi \sin \xi_{B1} + h_{12} \cos \xi_{B1}$$

$$x_{s21} = e_{11} \cos \xi_{B1} \cos \psi \cos \alpha_{B2} + q_{22} \cos \alpha_{B1} - h_{22} \sin \xi_{B2} \sin \alpha_{B2}$$

$$y_{s21} = e_{11} \cos \xi_{B1} \cos \psi \sin \alpha_{B2} + q_{22} \sin \alpha_{B2} + h_{22} \sin \xi_{B2} \cos \alpha_{B2}$$

$$z_{s21} = e_{11} \cos \xi_{B1} \cos \psi \sin \xi_{B1} - h_{22} \cos \xi_{B2}$$

$$x_{s22} = e_{22} \cos \xi_{B2} \cos \alpha_{B2} + q_{22} \cos \alpha_{B2} - h_{22} \sin \xi_{B2} \sin \alpha_{B2}$$

$$y_{s22} = e_{22} \cos \xi_{B2} \sin \alpha_{B2} + q_{22} \sin \alpha_{B2} + h_{22} \sin \xi_{B2} \cos \alpha_{B2}$$

$$z_{s22} = e_{22} \cos \xi_{B1} - h_{22} \cos \xi_{B2}$$

In these formulae the angles  $\alpha_{B1}$  and  $\alpha_{B2}$  are angles which lie in the horizontal plane and which are enclosed by the X axis and the oblique distances  $e_{11}$  and  $e_{22}$  projected into the horizontal plane, wherein  $\psi = \alpha_{B2} - \alpha_{B1}$  and which angles are measured using the angle measuring systems of the video tachymeter.

These coordinates are coordinates of the four supporting points  $S_{11}$ ;  $S_{12}$ ;  $S_{21}$ ;  $S_{22}$  of the coordinate system with the origin OP of the coordinates in the point of intersection of the vertical axis StA and the tilt axis KA. Following known mathematical principles, it is possible from the coordinates for the support points  $S_{11}$  and  $S_{22}$  to



calculate the equation of a straight line  $g_1$  and from the coordinates for the support points  $S_{12}$  and  $S_2$  to calculate the equation of a straight line  $g_2$ . The point of intersection of these two straight lines  $g_1$  and  $g_2$  is the object-point  $P$ , the coordinates of which were to be determined.

In the same manner, the coordinates of other object-points imaged and/or marked on the target images  $M_1$  and  $M_2$  are determined.

Figure 10 illustrates a video image traverse composed of the target images  $A_i$  ( $i = 1$  to 6) with a recorded survey traverse of the base points  $B_i$  ( $i = 1$  to 6) which were recorded by the camera of the video tachymeter from two different tachymeter stations  $StP_1$  and  $StP_2$ . A video tachymeter is disposed in each case in these tachymeter stations whose coordinates are known or a video tachymeter is positioned one behind the other in these tachymeter stations. In this manner, target images starting from the one video tachymeter stationed in the first tachymeter station  $StP_1$  and comprising at least two base points are recorded by the video camera and stored in the computer, wherein in each case one of the at least two base points (e.g. the points  $B_2$  or  $B_3$  in Figure 9) lies on the two adjacent target images. As is evident from Figure 9,  $B_1$  and  $B_2$  lie on the target images  $A_1$  and  $A_2$ ;  $B_2$  lies on the target images  $A_1$ ,  $A_2$  and  $A_3$ ;  $B_3$  lies on the target images  $A_2$ ,  $A_3$  and  $A_4$ ;  $B_4$  lies on the target images  $A_3$ ,  $A_4$  and  $A_5$ ;  $B_5$  lies on the target images  $A_4$ ,  $A_5$  and  $A_6$  and  $B_6$  lies on the target images  $A_5$  and  $A_6$ , wherein the target images  $A_4$ ,  $A_5$  and  $A_6$  are created from

the tachymeter station  $StP_2$ .

As is further evident from Figure 9, the base point  $B_4$  is provided both on the target image  $A_4$ , which is recorded by the tachymeter station  $StP_1$ , and also on the target image  $A_4$ , which is recorded by the tachymeter station  $StP_2$ , so that it is guaranteed that the survey traverse consisting of the base points  $B_i (i = 1 \text{ to } 6)$  is continued.

In order to continue with the survey traverse of target images (not illustrated), target images comprising at least two base points are likewise produced from further tachymeter stations  $StP_3$  to  $StP_n$ , and in each case at least one common base point is present on two adjacent target images. In this manner, a survey traverse of video images commenced in the tachymeter station  $StP_1$  is continued by the second tachymeter station  $StP_2$ .

When recording the target images  $A_i$ , the corresponding coordinates or variables, distance  $e_i$  from the corresponding tachymeter station  $StP_i$  to the individual base points  $B_i$ , the horizontal angles  $\psi_i$  and the vertical angles  $\xi_i$  to the base points  $B_i$  are determined using the distance and angle measuring devices provided in the video tachymeter. It is then possible from these determined parameters and other variables derived and obtained from the target images to determine the coordinates of object-points  $P_i$ , in the manner explained in connection with Figure 8.

CLAIMS

1. A method for determining the spatial coordinates of at least one object point  $P_i$  from the coordinates of at least two base points which serve as reference points and which do not lie in one plane with the aid of a video tachymeter which is disposed in one recording station, can pivot about a vertical axis, and comprises a distance measuring arrangement, a video camera having a CCD matrix, a sighting device and angle measuring devices, wherein the video camera can tilt about a horizontal axis, wherein,
  - the base points are marked in the terrain, are sighted using the sighting device and their coordinates are measured with the aid of the distance measuring arrangement and the angle measuring devices,
  - that in addition in each case a target image is recorded by the video camera and stored and said target image contains the marked base points and the object points and
  - that the coordinates of the object points are then determined from their image point coordinates in the target images and from the marked base points which have been determined using the tachymeter.
2. A method according to claim 1, wherein the base points determined by the tachymeter are marked in the recorded target images.

3. A method according to claim 1 and 2, wherein the object points  $P_i$  to be measured are selected at the target point on a target image transmitted to a screen provided there or are subsequently selected during the in-house processing using the recorded and stored target images.
4. A method for determining the spatial coordinates of at least one object point  $P_i$  from the coordinates of at least two base points, which serve as reference points, which are determined with the aid of a video tachymeter which is disposed in a recording station, can pivot about a perpendicular vertical axis  $StA$ , is provided with a recording which can tilt about a horizontal tilt axis  $KA$  for a distance measuring arrangement, with a video camera having a CCD matrix, with a sighting device and with angle measuring devices, comprising the following method steps:
  - Sight the at least two base points  $B_1$  and  $B_2$  lying in the object space by means of the video tachymeter which is disposed in a recording station, can rotate about the vertical axis  $StA$  by a horizontal angle  $\psi$  and comprises a video camera which can tilt about the horizontal tilt axis  $KA$  by the vertical angle  $\xi$  and determine the oblique distances  $e_{11}$  and  $e_{22}$  to the at least two base points  $B_1$  and  $B_2$  with the aid of the distance measuring arrangement of the video tachymeter,

- Create and store two target images containing in each case at least two base points  $B_1$  and  $B_2$ , wherein the video camera is aligned in each case so that the image  $B'_1$  or  $B'_2$  of the respective sighted base points  $B_1$  or  $B_2$  lies in the respective main point  $H'_1$  or  $H'_2$  of its lens,
  
  - Determine the coordinates  $x$ ,  $y$  and  $z$  of at least one object point  $P_1$  which lies in the space recorded by the target images and is marked during the recording or on the recorded target images with the aid of the target image coordinates  $q'_{11}$ ;  $q'_{12}$ ,  $h'_{11}$ ;  $h'_{12}$  of the selected object point  $P_1$  in the object space and imaged on the CCD matrix, from the oblique distances  $e_{11}$  and  $e_{22}$ , the measured horizontal angle  $\psi$ , the vertical angles  $\xi_1$  and  $\xi_2$ , of a device constant  $\Delta e$  and the focal length  $f$  of the lens of the video camera, wherein these coordinates  $x$ ,  $y$  and  $z$  are coordinates of a coordinate system having the axes  $X$ ;  $Y$ ;  $Z$  with their coordinates originating in the point of intersection of the tilt axis and the vertical axis  $StA$  of the video tachymeter and the vertical axis  $StA$  is perpendicular on the  $X$ - $Y$  plane and fixes the direction of the  $Z$  axis.
5. A method according to claim 4, having the following method steps:
- a. sight a first base point  $B_1$  by adjusting the axis of the video camera at a first horizontal angle  $\psi_1$  and at

a first vertical angle  $\xi_1$  with respect to the X-Y plane in the direction of the first base point  $B_1$  and measure the first vertical angle  $\xi_1$  and the first horizontal angle  $\psi_1$ , wherein the vertex of this vertical angle  $\xi_1$  and of this horizontal angle  $\psi_1$  lies in the tilt axis KA of the video tachymeter, record and store a first target image and measure the oblique distance  $e_{11}$  to this first base point  $B_1$  using a distance measuring arrangement which is disposed in a coaxial manner with respect to the axis of the video camera of the video tachymeter, wherein the video camera is aligned in such a manner that the image  $B'_1$  of the first base point  $B_1$  lies in the main point  $H'_1$  of the lens of the video camera and moreover contains the image  $B'_2$  of the second base point  $B_2$ ;

- b. pivot the video tachymeter by a horizontal angle  $\psi$  formed by the two base points  $B_1$  and  $B_2$  and the vertical axis StA of the video tachymeter, wherein the vertex of this angle lies on the site of the vertical axis StA;
- c. sight a second base point  $B_2$  by adjusting the axis of the video camera at a second horizontal angle  $\psi_2$  and at a second vertical angle  $\xi_2$  with respect to the X-Y plane in the direction of the second base point  $B_2$  and measure the second vertical angle  $\xi_2$  and the second horizontal angle  $\psi_2$ , wherein the vertex of the second vertical angle  $\xi_2$  lies in the tilt axis KA of the tachymeter, record and store a second target image and

measure the oblique distance  $e_{22}$  to this second base point  $B_2$  using the distance measuring arrangement of the video tachymeter, wherein the video camera is aligned in such a manner that the image  $B'_2$  of the second base point  $B_2$  lies in the main point  $H'_2$  of the lens of the video camera and moreover contains the image  $B'_1$  of the first base point  $B_1$ ;

- d. determine the coordinates of any object points  $P_i$  contained in the recorded target images and lying in the space with the aid of the coordinates of the two base points  $B_1$  and  $B_2$  by means of:

da Marking the desired object point  $P_i$  during the recording in the respective video image or  
Marking the desired object point  $P_i$  in the recorded video images by clicking the mouse,

db measuring the target image coordinates  $q'_{11}$ ;  $q'_{12}$ ,  $h'_{11}$ ;  $h'_{12}$  of the object point  $P_i$  in the recorded target images  $(M'_1, M'_2)$ ,

dc converting the target image coordinates  $q'_{11}$ ;  $q'_{12}$ ,  $h'_{11}$ ;  $h'_{12}$ , lying in the plane of the CCD matrix

of the object point  $P_i$  into analogue coordinates  $q'_{11}$ ;  $q'_{12}$  and  $h'_{11}$ ;  $h'_{12}$  lying in the object space with the aid of:

- the measured oblique distances  $e_{11}$  and  $e_{22}$ , corrected with a device constant  $\Delta e$ ,
- the measured image coordinates  $q'_{11}$ ;  $q'_{12}$  and  $h'_{11}$ ;  $h'_{12}$
- the focal length  $f$  of the lens of the video

camera,

wherein  $i$  = a function of the number of the object points,

dd Calculating the parameters  $q_{11}; q_{12}; h_{11}; h_{12}; q_{21}; h_{21}; q_{22}; h_{22}$  pf of support points  $S_{11}; S_{12}; S_{21}; S_{22}$ , which define the straight lines  $g_1$  and  $g_2$ , with the aid of

- the image coordinates  $q'_{11}; q'_{12}; h'_{11}; h'_{12}$  converted in the object space
- the measured oblique distances  $e_{11}$  and  $e_{22}$ ,
- the measured horizontal angle  $\psi$ ,
- the measured vertical angles  $\xi_1$  and  $\xi_2$
- and the distances  $e_{12}$  and  $e_{21}$  derived from the horizontal angle  $\psi$ , from the oblique distances  $e_{11}$  and  $e_{22}$  and the vertical angles  $\xi_1$  and  $\xi_2$ ,

de Transforming these support point parameters into the coordinates of the coordinate system  $X; Y; Z$  with its origin in the point of intersection of the vertical axis  $StA$  and the tilt axis  $KA$ ,

e Calculate the coordinates  $x; y$  and  $z$  of the object point  $P_1$  with the origin of the coordinates of the said coordinate system, which origin lies in the point of intersection of the tilt axis  $KA$  and vertical axis  $StA$  of the video tachymeter, with the aid of the coordinates of the support points  $S_{11}; S_{12}; S_{21}; S_{22}$  by determining the point of intersection of the straight lines  $g_1$  and  $g_2$  which are defined by the support points  $S_{11}; S_{12}$  and  $S_{21}; S_{22}$ .



6. A method according to at least one of the preceding claims, wherein a survey traverse consisting of object points  $P_i$  is determined or fixed by a first station of the tachymeter with the aid of base points and the said survey traverse is continued by a second station of the tachymeter.
7. A method according to claim 6, wherein:
  - that target images  $M'_1$  and  $M'_2$  having at least two base points  $B_i$  are recorded by the video camera starting at a first tachymeter station and are stored in a computer, wherein in each case one of the two base points is imaged on two adjacent target images,
  - that target images having at least two base points  $B_i$  are likewise recorded by following, adjacent-lying second to nth tachymeter stations and in each case a common base point is imaged on two adjacent target images in such a manner
  - that at least one identical base point is imaged on two adjacent target images, which have been recorded by two adjacent tachymeter stations,
  - and that with the aid of the coordinates of the base points  $B_i$  the coordinates of the object points  $P_i$  imaged on the target images are determined.
8. A method according to at least one of the preceding claims, wherein an image evaluating device controls an automatic focussing arrangement in such a manner that

in one focussed position of the CCD matrix associated with an object plane, the target image coordinates of the desired object point  $P_i$  are measured, wherein the base points  $B_1$  and  $B_2$ , whose images  $B'_1$  and  $B'_2$  lie in the target image planes  $M'_1$  and  $M'_2$ , are sighted.

9. An arrangement for determining the spatial coordinates of at least one object point comprising:
  - in the measuring station an electronic tachymeter having an automatic sighting device and a transmitter, wherein the electronic tachymeter can pivot about a vertical axis, a distance measuring arrangement which can tilt about a tilt axis, a video camera having a CCD matrix, a sighting device and angle measuring devices for the purpose of measuring horizontal and vertical angles,
  - and provided in the target point are a target rod, which comprises a reflector, a radio, a receiver and the graphic field book which has storage elements, wherein:
    - that at least one part of the ray path of the distance measuring arrangement is disposed coaxially with the optical axis of the video camera,
    - that a tube which can be controlled in dependence upon the distance measured by the distance measuring arrangement or can be adjusted manually according to the sharpness or the contrast of the

video image in the direction of the optical axis and which comprises the CCD matrix is provided for focussing the CCD matrix,

- and that an image processing system is provided for recognising object points and specifying said object points as object points with a predetermined position.

10. An arrangement according to claim 9, wherein the tube comprising the CCD matrix is displaced in the direction of the optical axis by a drive which is computer-controlled according to an algorithm.
11. An arrangement according to claim 10, wherein the respective displacement path of the tube comprising the CCD matrix is calculated by the computer according to the distances determined by the distance measuring arrangement to the respective sighted base point.
12. An arrangement according to at least one of claims 10 and 11, wherein the displacement path when focussing the CCD matrix is derived by virtue of an image transformation according to maximum contrast or maximum sharpness to an object point plane lying between the target image planes of the base points.
13. An arrangement according to any of claims 9 to 12, wherein the target rod comprises in the target point a receiver, a radio and a computer with an additional target image screen,

and that the target image received in the measuring point is transmitted between the measuring station and the target point.

14. A method for obtaining the spatial co-ordinates of an object point substantially as hereinbefore described with reference to the accompanying drawings.
15. An arrangement for determining the spatial co-ordinates of an object point, substantially as hereinbefore described with reference to the accompanying drawings.



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Application No: GB 0011378.7  
Claims searched: 1, 4

Examiner: Michael Walker  
Date of search: 19 December 2000

## Patents Act 1977 Search Report under Section 17

### Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.R): G1F

Int Cl (Ed.7): G01C 3/00, 3/02; 15/00

Other: On-line: EPODOC, WPI, JAPIO

### Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
A	EP 0977011 A1 (ZEISS)	
A	JP 8327352 A (NIKON)	
A	DE 3628350 A (MAYR)	

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